Utah Geological Survey
a division of
Utah Department of Natural Resources

Plate 1
Utah Geological Survey Open-File Report 502
Interim Geologic Map of the Henrie Knolls Quadrangle

Base from U.S. Geological Survey,
Henrie Knolls Quadrangle, 1985

SCALE 1:24,000

1 0.5 0 1 2 Miles

Fieldwork by authors in 1992 and 2006-07
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Interim Geologic Map of the Henrie Knolls Quadrangle, Garfield, Iron, and Kane Counties, Utah

by
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UTAH
QUADRANGLE LOCATION

1	2	3
4		5
6	7	8

1 Bean Head
2 Paugwash Lake
3 Haycock Mountain
4 Navajo Lakes
5 Asay Bench
6 Straight Canyon
7 Strawberry Point
8 Long Valley Junction

ADJOINING 7.5' QUADRANGLE NAMES

MAP UNIT DESCRIPTIONS

QUATERNARY

Alluvial deposits

Qal1 **Modern stream deposits** (Holocene) - Moderately sorted sand, silt, clay, and pebble to boulder gravel deposited in active stream channels and flood plains; locally includes small alluvial-fan and colluvial deposits, and minor terraces as much as about 10 feet (3 m) above current base level; mapped along Mammoth Creek and the lower reaches of Tommy Creek in the northeast corner of the quadrangle; typically less than 20 feet (<6 m) thick.

Qat2-4 **Stream-terrace deposits** (Holocene to upper Pleistocene) - Moderately sorted sand, silt, clay, and pebble to boulder gravel that forms incised gently sloping surfaces above Mammoth Creek and Tommy Creek in the northeast corner of the quadrangle; deposited in stream-channel environment and locally includes small alluvial-fan and colluvial deposits; subscript denotes relative age and height above adjacent drainage; Qat2 ranges from about 5 to 10 feet feet (2-3 m), Qat3 ranges from about 10 to 20 feet (3-6 m), and Qat4 ranges from about 40 to 60 feet (12-18 m) above the adjacent Tommy and Mammoth Creeks; typically less than 20 feet (<6 m) thick.

Qaly **Younger stream deposits** (Holocene) - Similar to modern stream deposits (Qal1) and low-level stream-terrace deposits (Qat2), but mapped in upland drainages not well graded to Mammoth Creek, the principal stream on this part of the Markagunt Plateau; mapped along the upper reaches of Tommy Creek and in the Duck Creek and Strawberry Creek drainages; typically less than 20 feet (<6 m) thick.

Qalo **Older stream deposits** (Holocene to middle? Pleistocene) - Similar to stream-terrace deposits (Qat3 and Qat4), but mapped in upland drainages not well graded to Mammoth Creek, the principal stream on this part of the Markagunt Plateau; mapped along Tommy Creek and in the Duck Creek and Strawberry Creek drainages; typically less than 20 feet (<6 m) thick.

Qam **Alluvial-marsh deposits** (Holocene to upper Pleistocene) - Dark-yellowish-brown clay, silt, sand, and minor gravel lenses deposited in closed depressions on landslide deposits south of Houston Mountain (hill 10,054 in the northwest corner of the quadrangle); forms small marshy areas characterized by cattails and other hydrophilic vegetation; probably less than 10 feet (3 m) thick.

Qaf1 **Modern alluvial-fan deposits** (Holocene) - Poorly to moderately sorted, non-stratified, clay- to boulder-size sediment deposited principally by debris flows and debris floods at the mouths of active drainages; equivalent to the upper part of younger undifferentiated alluvial-fan deposits (Qafy), which are mapped in nearby quadrangles, but differentiated because they form smaller, isolated fans; probably less than 30 feet (<9 m) thick.

Qaf2 **Older alluvial-fan deposits** (Holocene) - Similar to modern alluvial-fan deposits (Qaf1), but now forms inactive, incised surface cut by level-2 stream-terrace deposits (Qat2) in the lower reaches of Tommy Creek; equivalent to the older, lower part of younger undifferentiated alluvial-fan deposits (Qafy), which are mapped in nearby quadrangles; probably less than 30 feet (<9 m) thick.

Qafo **Oldest alluvial-fan deposits** (upper to middle? Pleistocene) - Poorly to moderately sorted, non-stratified, clay- to boulder-size sediment that forms incised remnants in the upper part of Tippets Valley and near Tommy Creek; both deposits contain boulders of basalt (probably the Houston Mountain lava flow), Claron Formation limestone and sandstone, and rare chalcedony fragments over a heavily vegetated surface; thickness uncertain, but may be as much as 30 feet (9 m) thick.

Artificial deposits

Qf **Artificial fill deposits** (Historical) - Engineered fill and general borrow material used to construct roadbeds and small dams; although only the larger deposits are mapped, fill of variable thickness and composition should be anticipated in all developed or disturbed areas; typically less than 20 feet (6 m) thick.

Colluvial deposits

Qc **Colluvial deposits** (Holocene to upper Pleistocene) - Poorly to moderately sorted, angular, clay- to boulder-size, locally derived sediment deposited by slope wash and soil creep on moderate slopes and in shallow depressions; locally grades downslope into deposits of mixed alluvial, colluvial, and eolian origin; mapped only where it conceals contacts or fills broad depressions; even so, the Claron and Brian Head Formations shed enormous amounts of colluvium, such that a skirt of heavily vegetated colluvium, unmapped because it forms a veneer with poor geomorphic expression, typically envelops at least the lower part of steep slopes along their outcrop belt; typically less than 20 feet (6 m) thick.

Mass-movement deposits

Qms **Landslide deposits** (Historical? to upper Pleistocene?) - Very poorly sorted, locally derived material deposited by rotational and translational movement; composed of clay- to boulder-size debris as well as large, partly intact, bedrock blocks; characterized by hummocky topography, numerous internal scarps, chaotic bedding attitudes, and several small ponds, marshy depressions, and meadows; large landslide complex mapped in the northwest corner of the quadrangle on the south and east flanks of hill 10,054 (Houston Mountain) has a basal slip surface in the landslide-prone Brian Head Formation, which is here capped by the Houston Mountain lava flow; this landslide deposit includes large blocks of the Houston Mountain lava flow as much as several meters in size that are both widely scattered and clustered on hillocks; smaller landslides in the Claron Formation are mapped immediately to the south, west of Tippets Valley; undivided as to inferred age because new research shows that even landslides with subdued morphology (suggesting that they are older, weathered, and have not moved recently) may continue to exhibit slow creep or are capable of renewed movement if stability thresholds are exceeded (Francis Ashland, Utah Geological Survey, verbal communication, April 2006); age and stability determinations require detailed geotechnical investigations; query indicates large slump blocks on the east side of Houston Mountain that may exhibit incipient failure; thickness highly variable, but typically several tens of feet or more thick.

Qmt **Talus deposits** (Holocene to upper Pleistocene) - Very poorly sorted, angular cobbles and boulders and finer-grained interstitial sediment deposited principally by rock fall on or at the base of steep slopes; mapped in the upper reaches of Tommy Creek where it consists of basaltic blocks derived from the Navajo Lake lava flow; likely less than 20 feet (6 m) thick.

Mixed-environment deposits

Qac **Alluvial and colluvial deposits** (Holocene to upper Pleistocene) - Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment deposited in swales and small drainages by fluvial, slope-wash, and creep processes; generally less than 20 feet (6 m) thick.

Qaco **Older alluvial and colluvial deposits** (upper Pleistocene) - Similar to mixed alluvial and colluvial deposits (Qac), but forms incised, isolated remnants in the northeast corner of quadrangle and in the upper reaches of the Tommy Creek drainage; probably about 10 to 20 feet (3-6 m) thick.

Qafc **Alluvial-fan and colluvial deposits** (Holocene to upper Pleistocene) - Poorly to moderately sorted, non-stratified, clay- to boulder-size sediment deposited principally by debris flows, debris floods, and slope wash at the mouths of active drainages and the base of steep slopes; locally reworked by small, ephemeral streams; forms coalescing apron of alluvial-fan and colluvial deposits impractical to map separately at this scale; typically 10 to 40 feet (3-12 m) thick.

Qca **Colluvial and alluvial deposits** (Holocene to middle Pleistocene) - Poorly to moderately sorted, angular, clay- to boulder-size, locally derived sediment deposited principally by slope wash in shallow depressions and in the upper reaches of small drainages, which is locally reworked by alluvial processes; distal, finer-grained parts typically form broad, open meadows; thickness uncertain, but likely less than about 10 feet (3 m) thick.

Qae **Alluvial and eolian deposits** (Holocene to upper Pleistocene) - Moderately to well sorted, mostly light-reddish-brown silt and sand deposited by sheetwash and ephemeral streams in small drainages and swales on the Henrie Knolls lava flow in the west-central part of the quadrangle; probably less than 10 feet (3 m) thick.

Qea **Eolian and alluvial deposits** (Holocene to upper Pleistocene) - Well sorted, light-reddish-brown silt and sand deposited by wind and reworked by sheetwash in swales on the Henrie Knolls lava flow in the southwest part of the quadrangle; probably less than 10 feet (3 m) thick.

Qaec **Alluvial, eolian, and colluvial deposits** (Holocene to upper Pleistocene) - Moderately sorted, light-reddish-brown and moderate- to dark-yellowish-brown silt and sand deposited in swales and small drainages on and adjacent to the Henrie Knolls lava flow in the west-central part of the quadrangle, where it locally includes gravelly lenses; the margins of the deposits include significant colluvium derived from adjacent slopes developed on the Claron Formation and basaltic lava flows; also mapped in Dry Valley, in the southwest corner of the quadrangle, where the distal margins of the deposit likely are interbedded with lacustrine and alluvial deposits (Qla); soils developed on this unit have an argillic horizon 1 to 1.5 feet (0.3-0.5 m) thick of moderate-reddish-brown sandy clay and clayey fine-grained sand; typically less than 10 feet (3 m) thick, although Duck Creek deposits are likely as much as 20 feet (6 m) thick.

Qla **Lacustrine and alluvial deposits** (Holocene to upper Pleistocene) - Moderately to well sorted, thinly bedded, yellowish-brown and light-gray, fine-grained sand, silt, and clay derived from adjacent Claron Formation slopes and deposited in the ephemeral Cow Lake in the southwest corner of the quadrangle; mostly conceals vesicular basalt that is likely part of the Duck Creek lava flow; probably less than 15 feet (4 m) thick.

Stacked unit deposits

Qac/Qbdc **Alluvial and colluvial deposits over the Duck Creek lava flow** (Holocene to upper Pleistocene/Pleistocene) - Mapped southwest of Bowers Flat, near the east-central edge of the quadrangle, where mixed alluvial and colluvial deposits mostly conceal the underlying Duck Creek lava flow; surficial cover generally less than 3 feet (1 m) thick.

Qc/Qbhk **Colluvial deposits over the Henrie Knolls lava flow** (Holocene to upper Pleistocene/Pleistocene) - Mapped in the east-central part of the quadrangle where mostly fine-grained colluvial deposits derived from the red member of the Claron Formation mostly conceal the underlying Henrie Knolls lava flow; surficial cover generally less than 6 feet (2 m) thick.

Qalo/Qbdc **Older stream deposits over the Duck Creek lava flow** (Holocene to middle? Pleistocene/Pleistocene) - Mapped near Duck Creek Sinks where older stream deposits mostly conceal the underlying Duck Creek lava flow; surficial cover generally less than 6 feet (2 m) thick.

Qalo/Qbsk **Older stream deposits over the Strawberry Knolls lava flow** (Holocene to middle? Pleistocene/Pleistocene) - Mapped along Strawberry Creek where older stream deposits mostly conceal the underlying Strawberry Knolls lava flow; surficial cover generally less than 6 feet (2 m) thick.

Qaco/Qbhk **Older alluvial and colluvial deposits over the Henrie Knolls lava flow** (upper Pleistocene/Pleistocene) - Mapped at Tippets Valley where scattered subrounded cobbles and boulders of basalt and Claron Formation limestone and sandstone poke through a densely vegetated surface, apparently concealing the underlying Henrie Knolls lava flow; surficial cover typically less than 6 feet (2 m) thick.

Qat4/Qbhk **Stream-terrace deposits over the Henrie Knolls lava flow** (upper Pleistocene/Pleistocene) - Mapped along the lower reaches of Tommy Creek where high-level stream-terrace deposits conceal the underlying Henrie Knolls lava flow; surficial cover typically less than 6 feet (2 m) thick.

Qc/Tbh Qc/Tbh**Colluvium over the Brian Head Formation** (Holocene to upper Pleistocene/Oligocene to Eocene) – Mapped on the west side of hill 10,054 (Houston Mountain) in the northwest corner of the quadrangle, where colluvium and possibly small landslide deposits conceal the underlying Brian Head Formation; colluvium includes large blocks of the Houston Mountain lava flow enclosed in a matrix of colluvium derived from weathered, tuffaceous Brian Head strata and oldest alluvial-stream deposits; surficial cover may exceed 20 feet (6 m) thick.

Qc/Tcwu **Colluvium over the upper limestone interval of the white member of the Claron Formation** (Holocene to upper Pleistocene/ Eocene to Paleocene?) – Mapped on the southwest side of hill 10,054 (Houston Mountain) in the northwest corner of the quadrangle, where colluvium conceals the underlying upper limestone interval of the white member of the Claron Formation; colluvium includes large blocks of the Houston Mountain lava flow enclosed in a matrix of colluvium derived from weathered, tuffaceous Brian Head strata and the upper limestone interval of the white member of the Claron Formation; surficial cover may exceed 10 feet (3 m) thick.

Basaltic lava flows

Basaltic lava flows in the Henrie Knolls quadrangle and adjacent area are part of the Western Grand Canyon basaltic field, which extends across the southwest part of the Colorado Plateau and adjacent transition zone in southwest Utah, northeast Arizona, and adjacent Nevada (Hamblin, 1963, 1970, 1987; Best and Brimhall, 1970, 1974; Best and others, 1980; Smith and others, 1999). This basaltic field contains hundreds of relatively small volume, widely scattered basaltic lava flows and cinder cones that range in age from late Miocene to Holocene. Lava flows in the Henrie Knolls quadrangle have not been radiometrically dated, but new $^{40}Ar/^{39}Ar$ ages are pending on the Henrie Knolls and Houston Mountain lava flows. Best and others (1980) reported a K-Ar age of 0.52 + 0.05 Ma for the Asay Knoll lava flow in the adjacent Asay Bench quadrangle. Stowell (2006) reported an $^{40}Ar/^{39}Ar$ maximum age of 2.78 + 0.16 Ma for sample 626BS1 (her "stage 1" basalt from the Miller Knoll area) in the adjacent Panguitch Lake quadrangle, although it is unclear exactly which lava flow this sample represents. Miller Knoll appears to be the principal vent for the Black Rock Valley lava flow, a remarkably youthful-appearing lava flow probably no older than late Pleistocene in age. Remnants of an older lava flow are present west and southwest of Miller Knoll, and it may be this flow that Stowell sampled; mapping now underway in the Panguitch Lake quadrangle should resolve this uncertainty. Stowell (2006) also reported an $^{40}Ar/^{39}Ar$ maximum isochron age of 0.60 + 0.25 Ma for sample 71SS2 (possibly the Hancock Mountain lava flow), also in the adjacent Panguitch Lake quadrangle.

Cinder cones in the Henrie Knolls quadrangle are well vegetated but lack significant rill erosion. Based on only minor incision adjacent to the lava flows and typically barren, rubbly surfaces, the Navajo Lake and Henrie Knolls lava flows are the youngest lava flows in the quadrangle. Still, both lava flows are locally well vegetated, particularly near their margins. Collapsed lava tubes are abundant on these flows, and, locally, lava flows have collapsed into sinkholes in the underlying Claron Formation.

Table 1 shows major- and trace-element geochemical data for these basaltic lava flows. Figure 1 is total alkali versus silica (TAS) classification diagram of LeBas and others (1986), which is used for rock names. Figure 2 shows selected geochemical variation diagrams.

Qbnl, Qbnlc **Navajo Lake lava flow and cinder cone** (Pleistocene) – Medium- to dark-gray basalt, basaltic andesite, and mugearite (sodium-rich basaltic trachyandesite) with olivine phenocrysts in an aphanitic to fine-grained groundmass; some lava flows contain common small plagioclase phenocrysts; lava flows (Qbnl) erupted from several vents marked by cinder cones in the northeast part of the adjacent Navajo Lake quadrangle (Moore and others, 2004) and from one smaller vent (Qbnlc) in this quadrangle about two miles (3 km) west of Tippets Valley; margins of flows typically form steep, blocky flow fronts 10 to 30 feet (3-9 m) high; cinder cones are well vegetated and lava flows are locally well vegetated, but more commonly barren with a rough, blocky surface; vegetated areas collect wind-blown sediment forming a sparse soil cover on parts of the flow; age unknown, but lava flows are likely late Pleistocene in age based on degree of incision and weathering; Moore and others (2004) considered the lava flow as probably Holocene in age; lava flows are typically several tens of feet thick, but likely exceed 200 feet (60 m) thick where they fill paleotopography.

Qbhk, Qbhkc **Henrie Knolls lava flow and cinder cones** (Pleistocene) – Medium- to dark-gray basalt with olivine phenocrysts in an aphanitic to very fine grained groundmass; some lava flows, particularly those near the middle of the outcrop belt between Duck Creek Sinks and Dry Camp Valley Spring, also contain common plagioclase phenocrysts and have a slightly coarser, fine-grained groundmass; lava flows that erupted from the northeasternmost group of cinder cones tend to be of basaltic andesite composition; forms coalescing lava flows (Qbhk) that erupted from at least 20 separate vents marked by cinder cones (Qbhkc), including Henrie Knolls, the largest two cones; cinder cones are strikingly aligned along a northeast trend, subparallel to mapped normal faults in the quadrangle, but no major fault has been identified along this trend; margins of flows typically form steep, blocky flow fronts 10 to 30 feet (3-9 m) high; the southernmost of the Henrie Knolls lava flows blocked the Navajo Lake and Dry Valley drainages, forming Navajo Lake and the intermittent Cow Lake; age unknown, but cinder cones are well vegetated and lava flows are both locally well vegetated but more commonly barren with a rough, blocky surface; $^{40}Ar/^{39}Ar$ age pending on sample HK092106-1; vegetated areas collect wind-blown sediment, forming a sparse soil cover on parts of the flow; north end of lava flow, at Tommy Creek, is overlain by level-4 stream-terrace deposits assumed to be of late Pleistocene age, thus lava flows are likely late Pleistocene in age; lava flows are typically several tens of feet thick, but likely exceed 200 feet (60 m) thick where they fill paleotopography.

Qbsk, Qbskc **Strawberry Knolls lava flow and cinder cone** (Pleistocene) – Medium- to dark-gray potassic trachybasalt with olivine phenocrysts in an aphanitic to very fine grained groundmass; lava flow (Qbsk) erupted from Strawberry Knolls (Qbskc), two cinder cones near the southeast corner of the quadrangle, and flowed mostly northeast along Strawberry Creek in the adjacent Asay Bench quadrangle (Moore and others, 1994); age unknown, but cinder cones are well vegetated and flow is incised by Strawberry Creek as much as 40 feet (12 m) at its downstream end; probably late to middle Pleistocene in age; lava flow is typically about 20 feet (6 m) thick, but is doubtless many tens of feet thick near the vent areas.

Qbdc **Duck Creek lava flow** (Pleistocene) – Medium-gray basalt with olivine phenocrysts and abundant small plagioclase phenocrysts in a fine-grained groundmass; location of vent unknown, but likely is concealed by the Henrie Knolls or Navajo Lake lava flows, and may be an early, more fluid phase of the Henrie Knolls lava flows; topography shows that lava flowed from west to east down the ancestral Duck Creek drainage, in the south-central part of the quadrangle; lava flow is typically partly concealed by a veneer of unmapped surficial deposits of alluvial, colluvial, and eolian origin; forms the comparatively smooth valley floor along Duck Creek and northeastward to at least the Bowers Flat area; age unknown, but constrained by the fact that it locally covers the Bowers Knoll lava flow and in turn is locally covered by the Henrie Knolls lava flow, thus is probably middle Pleistocene in age; maximum exposed thickness is about 15 feet (5 m) near Aspen Mirror Lake, but may be several tens of feet thick where it fills paleotopography in the Duck Creek drainage.

Qbbk **Bowers Knoll lava flow and cinder cone** (Pleistocene) – Medium-gray mugearite (sodium-rich basaltic trachyandesite) with abundant olivine phenocrysts and less common plagioclase and clinopyroxene phenocrysts in a fine-grained groundmass; erupted from Bowers Knoll in the adjacent Asay Bench quadrangle; forms rugged, heavily vegetated, blocky surface with steep flow fronts 40 feet (12 m) or more high; age unknown, but predates the Duck Creek lava flow, so is probably middle to early Pleistocene in age; Best and others (1980) reported a K-Ar age of 0.52 + 0.05 Ma for the nearby Asay Knoll lava flow, which exhibits a similar degree of incision and weathering; typically 40 feet (12 m) or more thick near flow margins, but may exceed 100 feet (30 m) thick near the central part of the flow.

unconformity

QUATERNARY-TERTIARY

QTr **Blocky residual deposit** (Holocene to Pliocene?) – A high (9300 to 9800 feet elevation) deposit present west of Tippets Valley where blocky remnants of the Houston Mountain lava flow (Tbhm) have been let down by erosion of underlying beds; angular to subangular blocks of the former lava flow, typically 3 feet (1 m) or less in diameter but locally as large as about 12 feet (4 m), tend to accumulate in swales, on ridge crests, and at and near the base of steep slopes; locally, the blocks form a basaltic pavement on the white member of the Claron Formation, but typically they are only widely scattered; other than uncommon small fragments of chalcedony, no other exotic rock types are present; probably formed as former basalt-capped hilltops succumbed to hillslope erosion, undermining the lava flow and leading to scattered resistant blocks being dispersed over underlying bedrock; unmapped colluvium derived from this unit blankets much of the underlying Claron Formation west of Tippets Valley and south of Tommy Creek; typically less than a few feet thick.

unconformity

TERTIARY

Tbhm **Houston Mountain lava flow** (Pliocene? to Miocene?) – Medium-gray basalt with olivine phenocrysts and minor pyroxene phenocrysts in a fine-grained groundmass; commonly platy weathering; unconformably overlies the Brian Head Formation (Tbh) and late Tertiary alluvial deposits (Ta) at Houston Mountain (hill 10,054 in the northwest corner of the quadrangle) and, 4 miles (6 km) to the south, the Claron Formation (Tcwl and Tcr) in the vicinity of Anderson Spring; also comprises the blocks of residual deposits (QTr) capping the hill west of Tippets Valley, and is involved in the large landslide complex (Qms) east of Houston Mountain; source vent unknown and margins of lava flow are entirely eroded away, but elevation of remnants suggests flow was derived from the north; $^{40}Ar/^{39}Ar$ age pending on sample HK092006-3; maximum exposed thickness is about 140 feet (43 m) at Houston Mountain.

Ta **Oldest alluvial-stream deposits** (Pliocene? to Miocene?) – Light-gray to white, moderately cemented pebbly conglomerate and gritstone present in one small exposure at the head of a landslide just southeast of Houston Mountain; clasts include subangular to subrounded Claron limestone and sandstone, black and gray chert, a variety of ash-flow tuffs of uncertain provenance but possibly including the Narrows Tuff Member of the Leach Canyon Formation, and chalcedony; neither upper nor lower contacts are exposed, but these deposits are presumed to represent fluvial channel deposits that were covered by the Houston Mountain lava flow; maximum exposed thickness is about 30 feet (9 m).

unconformity

Tbh **Brian Head Formation** (Oligocene to Eocene) – The Brian Head Formation is the oldest widespread Tertiary volcaniclastic unit in the region and is probably late Eocene to middle Oligocene in age; it disconformably overlies the white and red members of the Claron Formation on the Markagunt Plateau (Sable and Maldonado, 1997). Sable and Maldonado (1997) divided the Brian Head Formation into three informal units, ascending: (1) nontuffaceous sandstone and conglomerate, (2) a volcaniclastic unit with minor limestone and chalcedony, and (3) a volcanic unit, locally present, with volcanic mudflow breccia, mafic lava flows, volcaniclastic sandstone and conglomerate, and ash-flow tuff. Exposed parts of the Brian Head Formation in the Henrie Knolls quadrangle belong to the middle volcaniclastic unit. The underlying nontuffaceous sandstone and conglomerate unit, well exposed at Cedar Breaks National Monument, is completely concealed by colluvium and, if present in the Henrie Knolls quadrangle, is no more than about 60 feet (12 m) thick at Houston Mountain.

The Brian Head Formation underlies hill 10,054 (Houston Mountain) in the northwest corner of the quadrangle; it is nearly everywhere heavily vegetated and covered by colluvium, and is also involved in large landslide complexes on the south and east side of the mountain. Two small exposures are present, however, at the head of a landslide on the southeast side of Houston Mountain. These exposures reveal a light-yellowish-gray to white volcanic ash, mostly weathered to clay, and fine-grained tuffaceous sandstone, both of which are non-resistant and poorly exposed; maximum exposed thickness is about 40 feet (12 m), but outcrop patterns suggest that the formation may be as much as 300 feet (90 m) thick at Houston Mountain. Brian Head strata are not present to the south in this quadrangle, presumably having been eroded away prior to emplacement of the Houston Mountain lava flow.

disconformity

Claron Formation (Eocene to Paleocene?) – Mapped as three informal lithostratigraphic units described below: an upper white member, which is itself divided into an upper limestone interval and a lower sandstone, mudstone, and limestone interval, and the lower red member. The Claron Formation consists of mudstone, siltstone, sandstone, limestone, and minor conglomerate deposited in fluvial, floodplain, and lacustrine environments of an intermontane basin bounded by Laramide uplifts (Schneider, 1967; Goldstrand, 1990, 1991, 1992; Taylor, 1993; Ott, 1999). The red member, and to a much lesser extent the white member, were greatly modified by bioturbation and pedogenic processes, creating a stacked series of paleosols (Mullett and others, 1988a, b; Mullett, 1989; Mullett and Wells, 1990). The Claron Formation is typically forested and covered by colluvium, but it forms the Pink Cliffs, the uppermost riser of the Grand Staircase, and is spectacularly exposed at Cedar Breaks National Monument and near Cascade Falls, immediately west and southwest of the Henrie Knolls quadrangle, respectively. It is mostly nonfossiliferous and its age is poorly constrained as Eocene to Paleocene(?) (Goldstrand, 1994).

Tcw **White member** – Shown in cross section only. In this quadrangle, the white member is about 400 feet (120 m) thick; it is 360 feet (110 m) thick at Cedar Breaks National Monument (Hatfield and others, 2003), and 448 feet (137 m) thick in the adjacent Asay Bench quadrangle (Moore and others, 1994). Sinkholes are common in the white member to the west (Moore and others, 2004). Sinkholes, assumed to be in the white member but covered by collapsed parts of the Navajo Lake lava flow (Qbnl), are mapped in the northwest corner of the Henrie Knolls quadrangle.

Tcwu **Upper limestone interval of white member** – White, pale-yellowish-gray, pinkish-gray, and very pale orange micritic limestone and uncommon pelmicritic limestone, locally with intraformational rip-up clasts; locally contains very sparse charophytes and planispiraled snails; typically poorly bedded and knobby weathering; locally vuggy with calcite spar and commonly cut by calcite veinlets; lower half of interval forms a prominent ledge and is typically better exposed than the lower white limestone at the base of the white member, but upper half, on Houston Mountain, is not exposed; upper, disconformable contact with the landslide-prone Brian Head Formation is not exposed; in this quadrangle, the upper limestone interval of the white member is about 150 to 180 feet (45-55 m) thick; it is 45 feet (14 m) thick at Cedar Breaks (Moore and others, 2004) and 80 to 165 feet (24-50 m) thick in the adjacent Asay Bench quadrangle (Moore and others, 1994).

Tcwl **Lower sandstone, mudstone, and limestone interval of white member** – Basal part is a 30- to 40-foot-thick (10-12 m) micritic limestone interval similar to the upper limestone interval (Tcwu) of the white member; this lower limestone interval is locally well exposed, as near the Iron-Garfield County line in the SW1/4SW1/4SW1/4 section 7, T. 37 S., R. 7 W., Salt Lake Base Line and Meridian (SLBLM), and adjacent areas, where it forms a conspicuous cliff equivalent to the "lower white limestone" in the Cedar Breaks National Monument area, but in this quadrangle it typically weathers to poorly exposed ledgey slopes; southwest of hill 9295, in the SW1/4 section 12, T. 37 S., R. 7 W., the lower part contains white-weathering, clear to light-brown chalcedony, possibly in a single bed as much as 1 foot (0.3 m) thick. Upper part of Tcwl contains white, yellowish-gray, and moderate-yellowish-brown calcareous mudstone and lesser fine- to medium-grained sandstone and minor chert-pebble conglomerate that in this quadrangle everywhere weathers to a poorly exposed slope. Contact with upper limestone interval of the white member typically corresponds to the base of a steeper slope. In this quadrangle, the lower sandstone and limestone interval of the white member is about 220 to 250 feet (67-75 m) thick; Moore and others (1994) reported that their middle sandy unit is 175 to at least 220 feet (54-67 m) thick and that their lower white limestone is generally 85 to 120 feet (26-36 m) thick, but as much as 180 feet (55 m) thick, both in the adjacent Asay Bench quadrangle.

Tcr **Red member** - Alternating beds of varicolored and commonly mottled, pale-reddish-orange, reddish-brown, moderate-orange-pink, dark-yellowish-orange, grayish-pink, and similarly hued sandy and micritic limestone, calcite-cemented sandstone, calcareous mudstone, and minor pebbly conglomerate, that, in this quadrangle, generally weathers to colluvium-covered slopes, rounded ridges, and small hills. The colluvium typically is moderate-yellowish-brown silty, clayey sand that contains white limestone and pale-reddish-orange rock fragments and minor pebbles of black chert and brown quartzite. **Limestone** is poorly bedded, microcrystalline, generally sandy with 2 to 20 percent fine-grained quartz sand, and is locally argillaceous; contains common calcite veinlets, calcite spar-filled vugs, and stylolites; the limestone is also locally cavernous and sinkholes are common; contains very sparse small bivalves and planispiral gastropods; many of these limestone beds may be calcic paleosols (Mullett and others, 1988a, b; Mullett, 1989; Mullett and Wells, 1990). **Sandstone** is thick-bedded, fine- to coarse-grained, calcareous, locally cross-bedded quartz arenite that typically weathers to sculpted or fluted ledges that pinch out laterally; sandstone locally contains pebble stringers. **Mudstone** is generally moderate reddish orange, silty, calcareous, contains calcareous nodules, and weathers to earthy, steep slopes between ledges of sandstone and limestone. **Pebbly conglomerate** is uncommon in this quadrangle, where it forms lenticular beds 5 to 15 feet (2-5 m) thick with limestone, quartzite, and chert clasts.

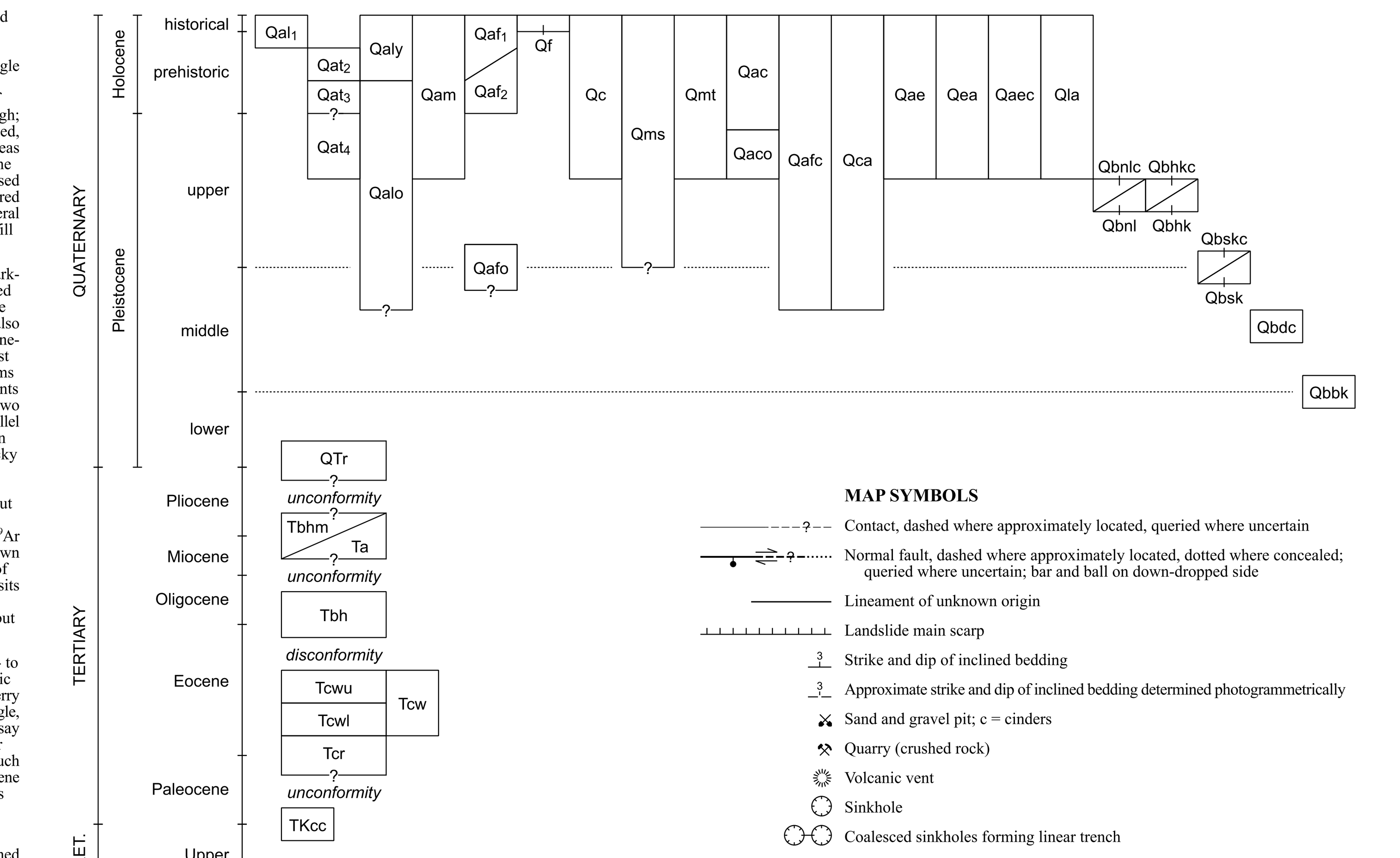
In the Henrie Knolls quadrangle, the upper contact of the red member is only well exposed near the Iron-Garfield County line in the SW1/4SW1/4SW1/4 section 7, T. 37 S., R. 7 W., SLBLM, and adjacent areas, where it corresponds to a pronounced color change from brightly colored reddish-orange mudstone and siltstone below to a conspicuous 30- to 40-foot-high (10-12 m) cliff of white to very pale orange micritic limestone (informally called the "lower white limestone" in the Cedar Breaks National Monument area). In areas of discontinuous outcrop, it is difficult to distinguish this limestone bed at the base of the white member (base of Tcwl) from other limestone beds in the upper part of the red member.

The lower contact of the Claron Formation is not exposed in the Henrie Knolls quadrangle. Moore and others (2004) noted that it corresponds to the base of a prominent, 62- to 75-foot-high (19-23 m), locally cavernous limestone cliff, below which lies mudstone and sandstone assigned to their informal formation of Cedar Canyon. The red member is about 1300 feet (400 m) thick at Cedar Breaks National Monument (Sable and Maldonado, 1997); the maximum exposed thickness in this quadrangle is about 500 to 600 feet (150-180 m).

TERTIARY TO CRETACEOUS

TKcc **Formation of Cedar Canyon** (Paleocene to Upper Cretaceous) – Shown in cross section only; 1070 to 1250 feet (325-380 m) thick (Moore and others, 2004).

CORRELATION OF MAP UNITS



MAP SYMBOLS

Contact, dashed where approximately located, queried where uncertain

Normal fault, dashed where approximately located, dotted where concealed; queried where uncertain; bar and ball on down-dropped side

Lineament of unknown origin

Landslide main scarp

3 Strike and dip of inclined bedding

3 Approximate strike and dip of inclined bedding determined photogrammetrically

Sand and gravel pit; c = cinders

Quarry (crushed rock)

Volcanic vent

Sinkhole

Coalesced sinkholes forming linear trench

Spring

HK091306-2 Rock sample location and number

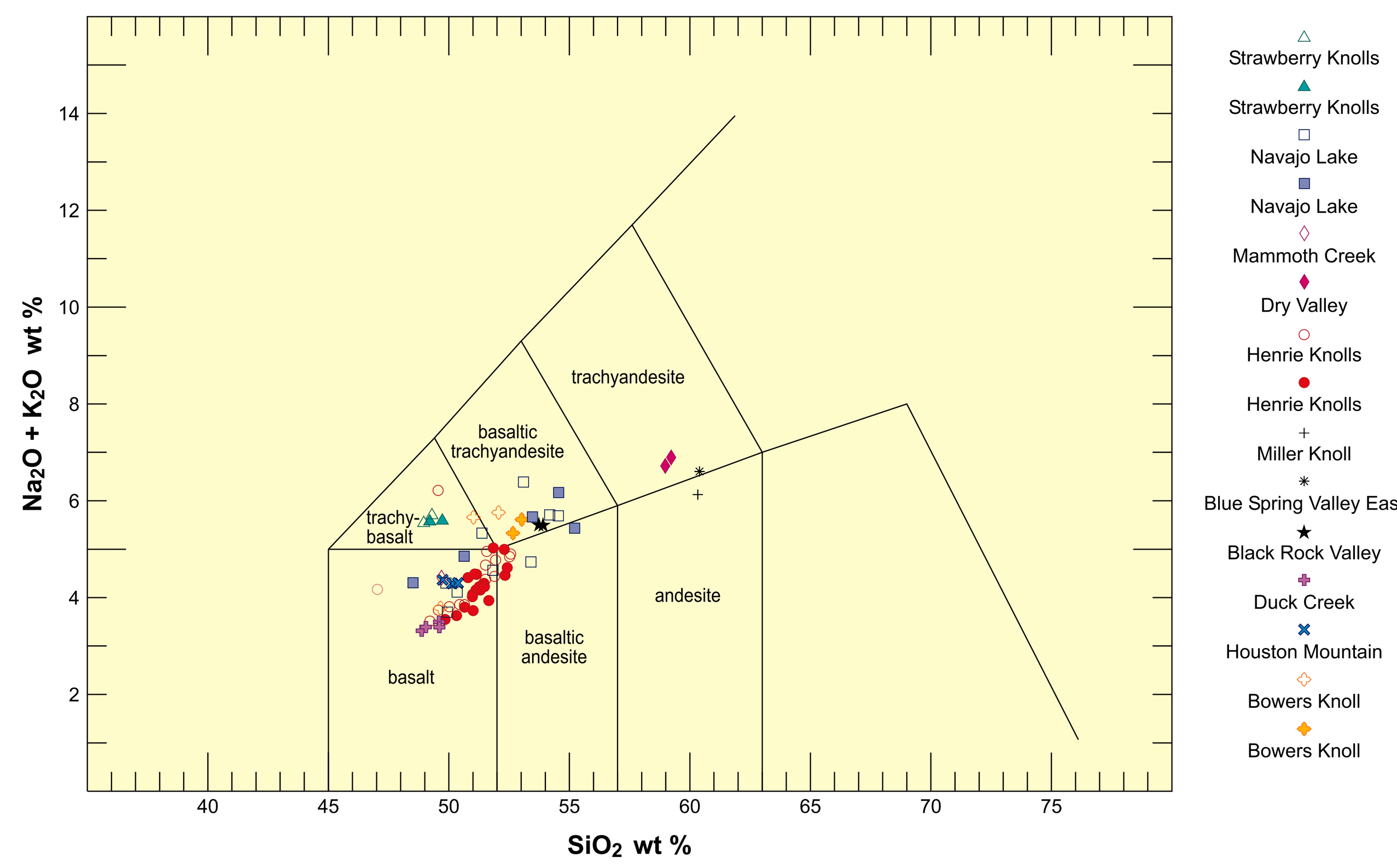


Figure 1. Basaltic rocks of the Henrie Knolls quadrangle and adjacent area on the total alkali versus silica (TAS) classification diagram of LeBas and others (1986). Solid symbols represent samples collected during this study; open symbols are from Moore and others (1994), Moore and others (2004), and Stowell (2006). The wide chemical variation in samples of the Navajo Lake (Qbnl) and Henrie Knolls (Qbhk) lava flows reflects the fact that these flows erupted from multiple vents and coalesced into flow complexes not practical to map separately at 1:24,000 scale.

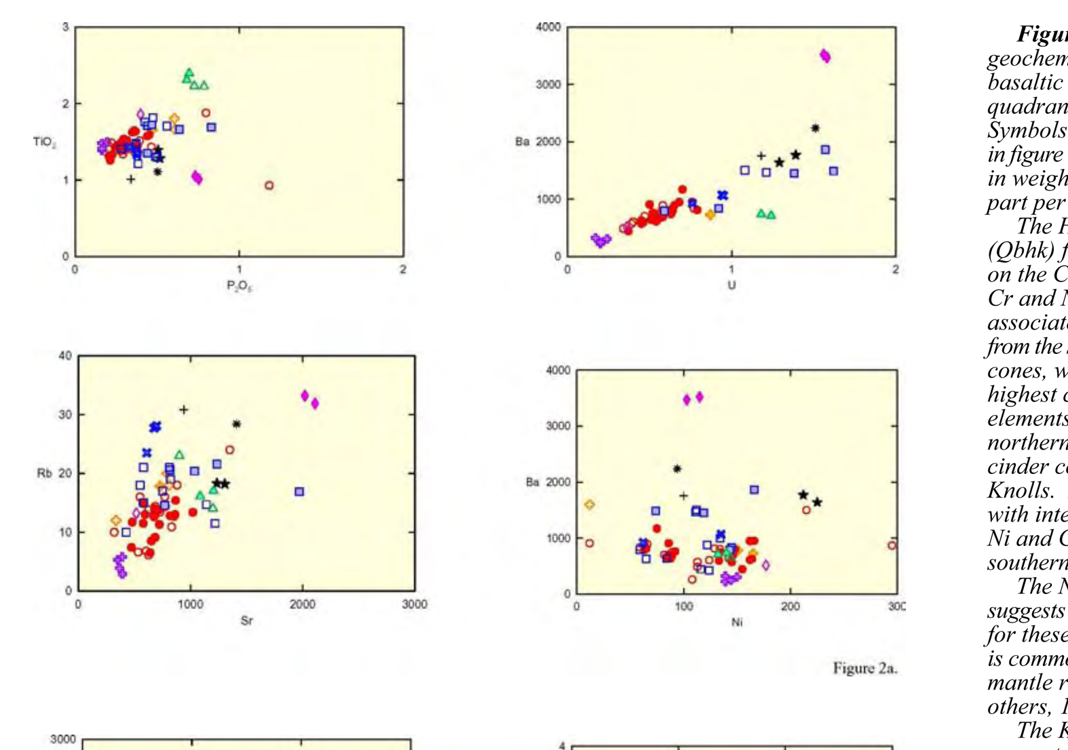


Figure 2a.

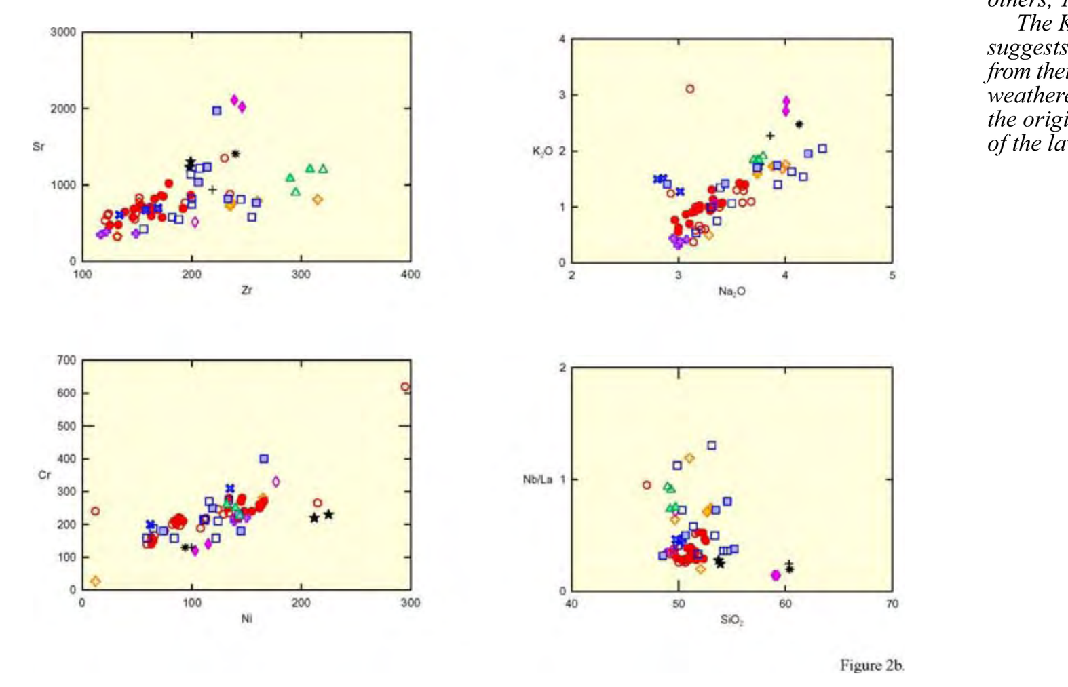


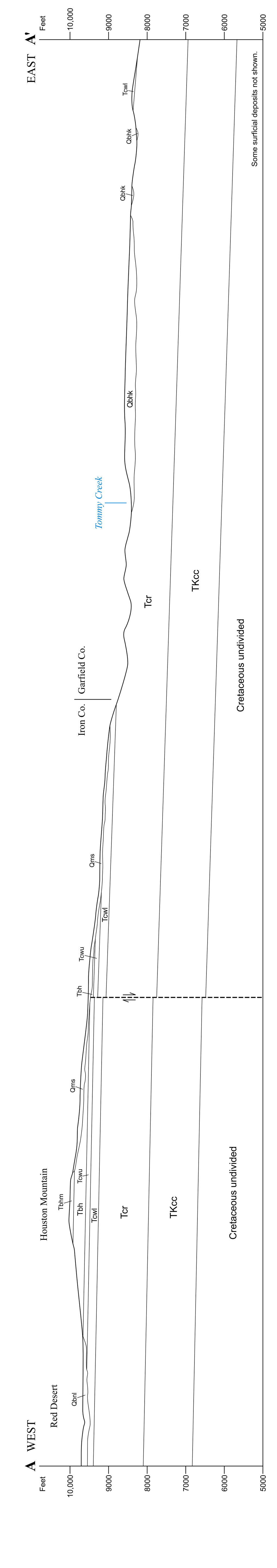
Figure 2b.

Figures 2a and 2b. Selected geochemical variation diagrams for basaltic rocks of the Henrie Knolls quadrangle and adjacent area. Symbols are the same as those used in figure 1. Major oxides are reported in weight percent, trace elements in part per million.

The Henrie Knolls lava flows (Qbhk) form three distinct clusters on the Cr versus Ni plot; the lowest Cr and Ni concentrations are associated with flows originating from the south-central group of cinder cones, whereas lava flows with the highest concentrations of these elements are associated with the northern and north-central group of cinder cones, including Henrie Knolls. Henrie Knolls lava flows with intermediate concentrations of Ni and Cr are associated with the southernmost group of cinder cones.

The Nb/La versus SiO_2 plot suggests a lithospheric mantle source for these basaltic rocks because Nb is commonly depleted in lithospheric mantle relative to La (Fritton and others, 1991).

The K_2O versus Na_2O plot suggests that samples that fall far from their respective group are likely weathered and may thus not reflect the original geochemical signature of the lava flow.



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LITHOLOGIC COLUMN

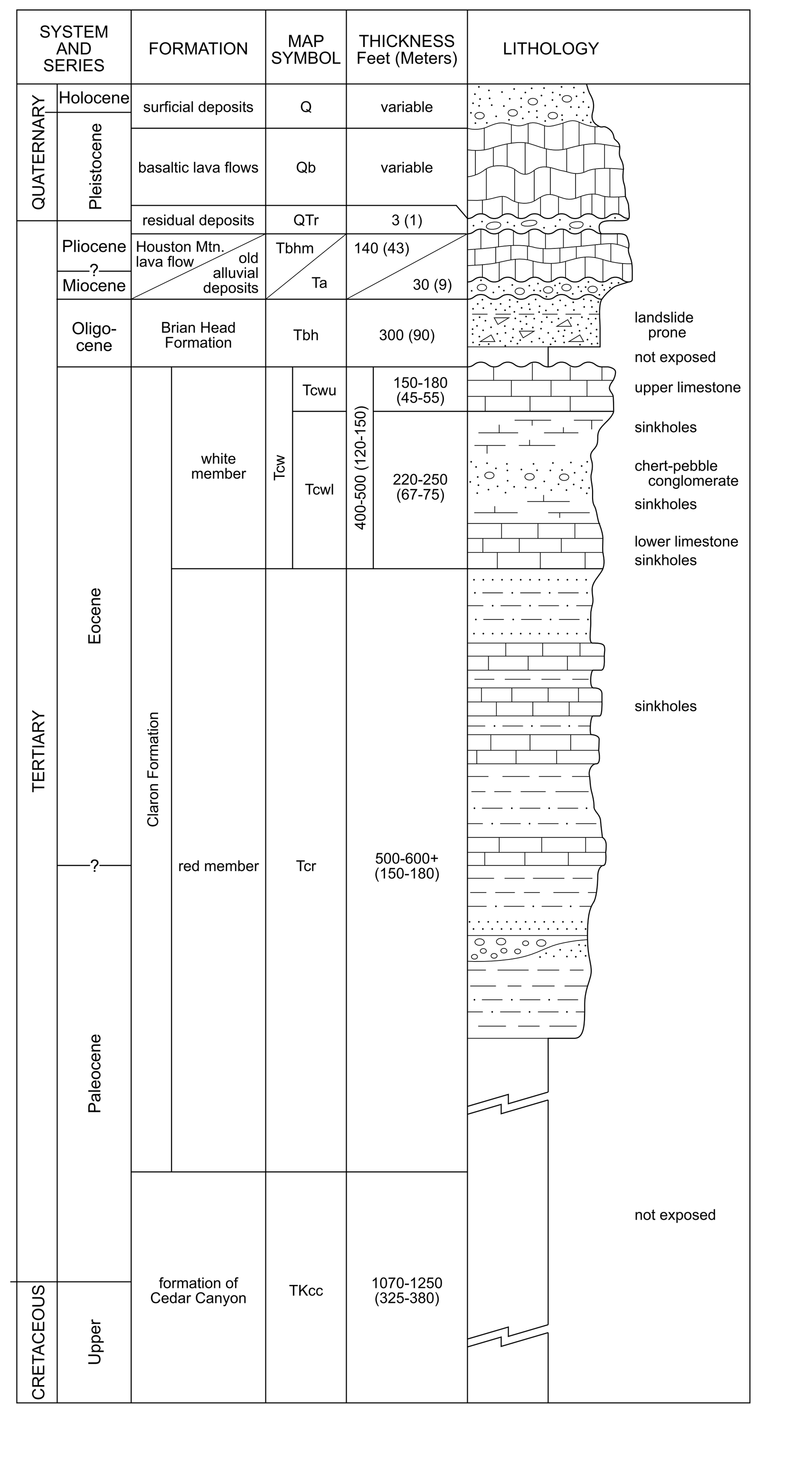

Table 1.